Seismic Analysis of TIIR Building by Equivalent Static Analysis method

A thesis Submitted by

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CERTIFICATE

This is to certify that the thesis entitled "SEISMIC ANALYSIS OF FOUR-STORY TIIR BUILDING USING EQUIVALENT STATIC METHOD" submitted by Mr. Mohammad Zia Arifizada . [Roll No.: 111CE0565] in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology Rourkela is an authentic work carried out by him under my supervision.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any degree or diploma.

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ABSTRACT

Developments in computer hardware and software have made analysis techniques that were formerly too expensive within the reach of most project budgets. Foremost among these has been equivalent static analysis. This method is beneficial for short story buildings. This approach defines a series of forces acting on a building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves. The response is read from a design response spectrum, given the natural frequency of the building (either calculated or defined by the building code). The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces (e.g. force reduction factors).

Shaking and ground rupture are the main effects created by earthquakes, mainly resulting damage to buildings and other rigid structures. The severity of the local effects depends on the complex combination of the earthquake magnitude, the distance from the epicenter and the local geological and geomorphological conditions

The ground motion is measured by ground acceleration .An earthquake may cause injury and loss of life, road and bridge damage, general property damage and collapse or destabilization of buildings. Present work deals with study of seismic analysis and design of Technology Innovation and Industry Relations.

.

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4. REINFORCED CONCRETE DESIGN

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5. SEISMIC EVALUATION

NOTATION AND ABBRAVIATION

IS = Indian Standard

LSA = Linear Static Analysis

RC = Reinforced Concrete

STAAD Pro. = Structural analysis and design for professional

2D = Two-dimension

3D = Three-dimension

E_c = Modulus of elasticity of concrete (MPa)

E_s = Modulus of elasticity of steel (MPa)

F_c = Compressive strength of concrete (MPa)

F_y = Yield strength of steel (MPa)

F_u = Tensile strength of steel (MPa)

G_c = Shear modulus of concrete (MPa)

G_s = Shear modulus of steel (MPa)

g = Acceleration of gravity (m/s^2)

x = Transverse direction

z = Longitudinal direction

αc = Thermal coefficient of concrete

α_c = Thermal coefficient of steel

γ_c = Unit weight of concrete (kN/m^3)

γ_s = Unit weight of steel (KN/m^3)

ν_c = Poisson ratio of concrete

ν_s = Poisson ratio of steel

ξ_c = Damping ratio of concrete (%)

NUPS =New Upper Primary School

NPS = New Primary School

ACR = Additional Classroom

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1 Introduction

1.1 General

An earthquake is the result of a sudden energy release in the earth's crust that creates seismic waves. The seismic activity of an area refers to the frequency, type and size of earthquakes experienced over a period of time. Buildings are subjected to ground motion. PGA (Peak Ground Acceleration), PGV (Peak Ground Velocity) PGD (Peak Ground Displacement), Frequency Content, and Duration which play predominant rule in studying the behaviour of buildings under seismic loads

It excludes shock waves caused by nuclear tests, man-made explosions, etc.

A list of natural and man-made earthquake sources:

Seismic Sources	
Natural Source	Man-made Source
• Tectonic Earthquakes • Volcanic Earthquakes • Rock Falls/Collapse of Cavity • Microseism	• Controlled Sources (Explosives) • Reservoir Induces Earthquakes • Mining Induces Earthquakes • Cultural noise (Industry, Traffic, etc.)

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building structure to earthquakes. It is part of the process of structural design.

- **Analysis methods are :**

  1 Equivalent static analysis

  2 Response spectrum analysis

  3 Linear dynamic analysis

  4 Nonlinear static analysis

  5 Nonlinear dynamic analysis

1.2 Equivalent static analysis

This approach defines a series of forces acting on a building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves. The response is read from a design response spectrum, given the natural frequency of the building (either calculated or defined by the building code). The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces (e.g. force reduction factors).

Since the Static Equivalent method is accurate and easy for short building especially for single story building so I have decided to analyze the given building in the

1.3 Response spectrum analysis

This approach permits the multiple modes of response of a building to be taken into account (in the frequency domain). This is required in many building codes for all except for very simple or very complex structures. The response of a structure can be defined as a combination of many special shapes (modes) that in a vibrating string correspond to the "harmonics". Computer analysis can be used to determine these modes for a structure. For each mode, a response is read from the design spectrum, based on the modal frequency and the modal mass, and they are then combined to provide an estimate of the total response of the structure. In this we have to calculate the magnitude of forces in all directions i.e. X, Y & Z and then see the effects on the building.. Combination methods include the following

Absolute - peak values re added together.

Square root of the sum of the squares (SRSS)

Complete quadratic combination (CQC) - a method that is an improvement on SRSS for closely spaced modes.

The result of a response spectrum analysis using the response spectrum from a ground motion is typically different from that which would be calculated directly from a linear dynamic analysis using that ground motion directly, since phase information is lost in the process of generating the response spectrum.

In cases where structures are either too irregular, too tall or of significance to a community in disaster response, the response spectrum approach is no longer appropriate, and more complex analysis is often required, such as non-linear static analysis or dynamic analysis.

1.4 Linear dynamic analysis

Static procedures are appropriate when higher mode effects are not significant. This is generally true for short, regular buildings. Therefore, for tall buildings, buildings with torsional irregularities, or non-orthogonal systems, a dynamic procedure is required. In the linear dynamic procedure, the building is modelled as a multi-degree-of-freedom (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix.

The seismic input is modelled using either modal spectral analysis or time history analysis but in both cases, the corresponding internal forces and displacements are determined using linear elastic analysis. The advantage of these linear dynamic procedures with respect to linear static procedures is that higher modes can be considered. However, they are based on linear elastic response and hence the applicability decreases with increasing nonlinear behavior, which is approximated by global force reduction factors.

In linear dynamic analysis, the response of the structure to ground motion is calculated in the time domain, and all phase information is therefore maintained. Only linear properties are assumed. The analytical method can use modal decomposition as a means of reducing the degrees of freedom in the analysis.

1.5 Nonlinear static analysis

In general, linear procedures are applicable when the structure is expected to remain nearly elastic for the level of ground motion or when the design results in nearly uniform distribution of nonlinear response throughout the structure. As the performance objective of the structure implies greater inelastic demands, the uncertainty with linear procedures increases to a point that requires a high level of conservatism in demand assumptions and acceptability criteria to avoid unintended performance. Therefore, procedures incorporating inelastic analysis can reduce the uncertainty and conservatism.

This approach is also known as "pushover" analysis. A pattern of forces is applied to a structural model that includes non-linear properties (such as steel yield), and the total force is plotted against a reference displacement to define a capacity curve. This can then be combined with a demand curve (typically in the form of an acceleration-displacement response spectrum (ADRS)). This essentially reduces the problem to a single degree of freedom (SDOF) system.

Nonlinear static procedures use equivalent SDOF structural models and represent seismic ground motion with response spectra. Story drifts and component actions are related subsequently to the global demand parameter by the pushover or capacity curves that are the basis of the non-linear static procedures**.**

1.6 Nonlinear dynamic analysis

Nonlinear dynamic analysis utilizes the combination of ground motion records with a detailed structural model, therefore is capable of producing results with relatively low uncertainty. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model and the modal responses are combined using schemes such as the square-root-sum-of-squares.

In non-linear dynamic analysis, the non-linear properties of the structure are considered as part of a time domain analysis. This approach is the most rigorous, and is required by some building codes for buildings of unusual configuration or of special importance. However, the calculated response can be very sensitive to the characteristics of the individual ground motion used as seismic input; therefore, several analyses are required using different ground motion records to achieve a reliable estimation of the probabilistic distribution of structural response. Since the properties of the seismic response depend on the intensity, or severity, of the seismic shaking, a comprehensive assessment calls for numerous nonlinear dynamic analyses at various levels of intensity to represent different possible earthquake scenarios. This has led to the emergence of methods like the Incremental Dynamic Analysis.

1.7 Objective and Scope

The present project deals with seismic analysis of RC building of Technology Innovation and Industry Relations (TIIR), by Equivalent static method using Structural Analysis and Design (STAAD Pro.) software and considering Indian Standard code 1893(2002).

1.8 Methodology

Design horizontal seismic coefficient (Ah) for a structure shall be determined by the following expression:

$$A_h = \frac{ZISa}{2Rg}$$

Where,

Z=Zone factor=0.16(for 3rd zone)

I=Importance factor=1.5(for important building)

R=Response reduction factor=5

Sa/g=Average response acceleration coefficient

For medium soil site

$$\frac{Sa}{g} = \begin{cases} 1 + 15T & 0.00 \le T \le 0.10 \\ 2.50 & 0.10 \le T \le 0.55 \\ \frac{1.36}{T} & 0.55 \le T \le 4.00 \end{cases}$$

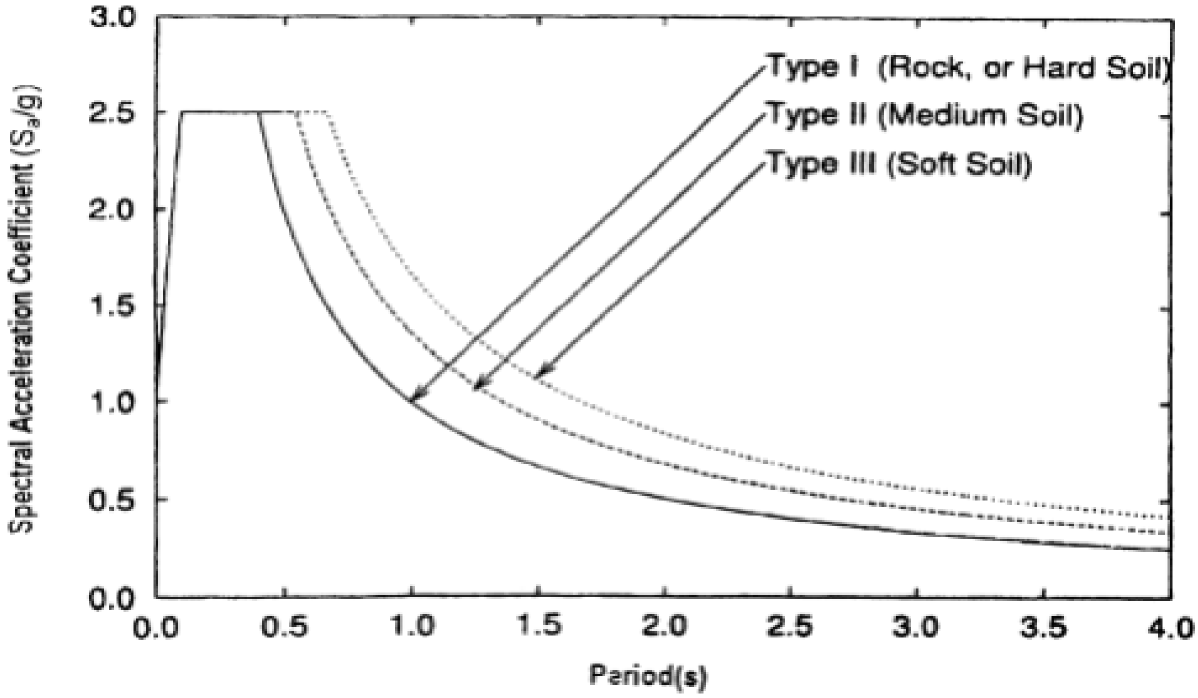

FIG. 2 RESPONSE SPECTRA FOR ROCK AND SOIL SITES FOR 5 PERCENT DAMPING

FIG.2 is taken from IS1893 (2002)

$T_a = 0.075h^{0.75}$

Where,

h= Height of building from the ground

Design Lateral Force

The total design lateral force or design seismic base shear (V_b) along any principal direction shall be determined by following expression

$$V_b = A_h W$$

Where,

$A_h =$ Design horizontal acceleration spectrum value as per 6.4.2 IS1893 using the fundamental natural period (T) as per 7.6 in the considered direction of vibration; and

$W =$ Seismic weight of the building as per 7.4.2 IS1893 (2002)

Finally the calculated lateral force are applied to the building and analyzed by structural analysis and design (STAAD) or (STAAD Pro.) software.

Distribution of Design Force

Vertical distribution of base shear to different floor

$$Q_i = V_B \cdot \frac{W_i \cdot h_i^2}{\sum_{j=1}^{n} W_j \cdot h_j \ 2}$$

Q_i = design lateral force at floor i

W_i = seismic weight of floor i

h_i = height of floor i measured from base; and

n = number of storeys in the building (the number of levels at which the masses are located).

2 literature review

2.1 General

1. J Laxmi Reddy (2009) did Earthquake analysis of School buildings

2. M. I. Adiyanto in 2008 analyzed a 3storey hospital building using STAAD Pro. Seismic loads were applied to the building. The dead loads and live loads are taken from BS6399:1997 and seismic loads intensity is based on equivalent static force procedure in UBC1994. Result showed that the building can withstand any intensity of earthquake. It means that the buildings are suitable to be built in any area located near the epicenter of the earthquake.

3. Aslam analysed in 2014 did (G+5) storey Hospital building in Agartala one the projects undertaken by L&T. The seismic analysis of the proposed building was done in the software ETABS, version- 9.7, which is one of the most advanced software in the structural design field. The loads applied on the structure was based on IS: 875 (part I) 1987[dead load] IS:875 (part II)-1987[live load],
IS:875(part III)-1987[wind load], IS:1893-2002
[Earthquake load]. Scale factor is calculated from the design base shear. (V_b) to the base shear calculated using fundamental time period (T_a).Once the analysis was completed all the structural components were designed according to Indian standard code IS:456-2000. This included footings, columns, beams, slabs, staircases and shear walls.

4. Mr.Ankur Agrawal in 2012 did seismic evaluation of institute building. There are many buildings which do not meet the current seismic requirement and suffer extensive damage during the earthquake. In 1960 when the institute building of NIT Rourkela was constructed, the seismic loading was not considered. The building is only deigned to take the dead and live loads. Evaluating the building for seismic conditions gives an idea whether the building is able to resist the earthquake load or not. Mr.Ankur Agrawal carried out the Demand Capacity Ratio (DCR) for beams and columns in order to evaluate the member for seismic loads. Since He did not find the reinforcement details of the building as it was more than 50 years old He have prepared Design-1 applying only DEAD and LIVE loads according to IS 456:2000 to estimate the reinforcement present in the building and assuming that this much reinforcement is present. In Design-2 seismic loads are applied and for this demand obtained from design-2 and capacity from design -1 the DCR is calculated. If demand is more than capacity member fails and vice versa.

2.2 Overview of literature

In the literature review, characteristics of ground motion plays vital rule in the seismic analysis of structures.

However, there are many other methods which are more accurate than equivalent static method but this method is easy and it does not take much time to analyze short buildings in different seismic zones.

3 Structural Modelling and analysis

3.1 Overview

The Technology Innovation and Industry Relations contains 15 working modules, one auditorium, two stores, one common facility, three stair cases, one electrical room , one big display area and other necessary rooms.

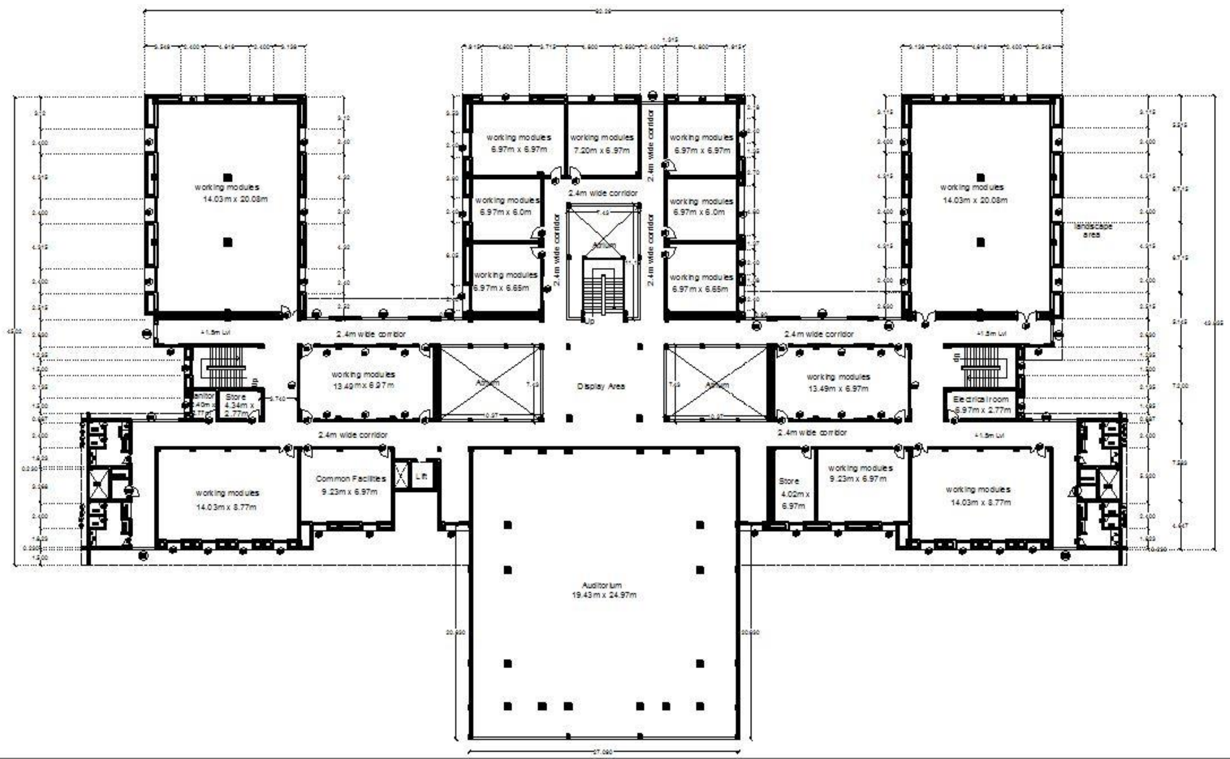

Fig3.1, Plan of TIIR building

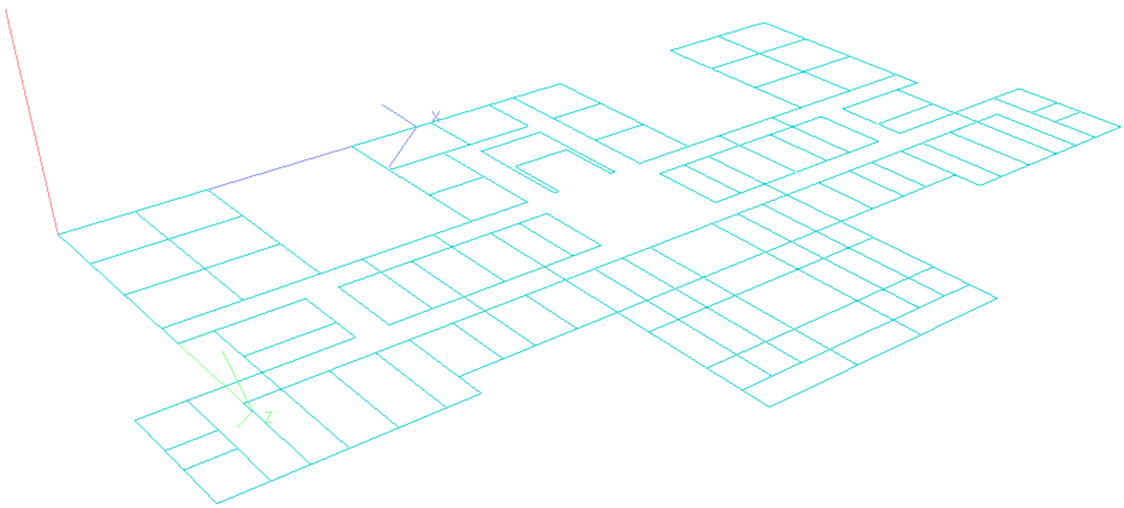

Fig3.2, Plan of TIIR building

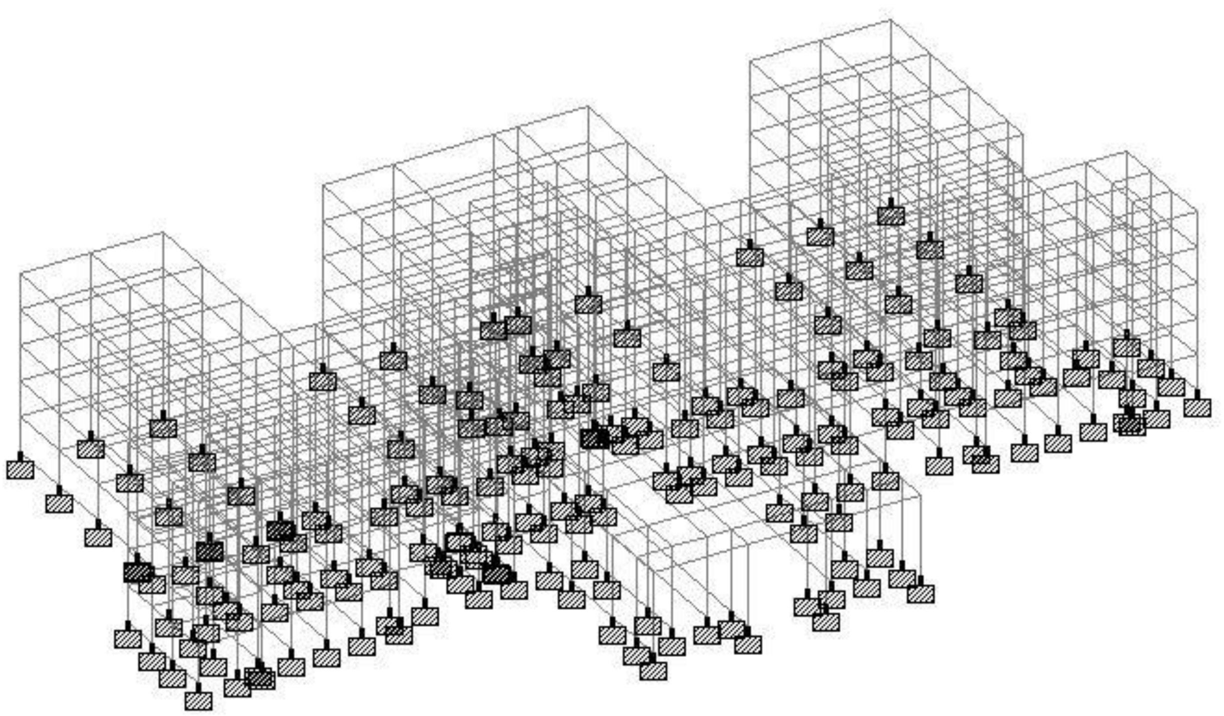

Fig3.3, Isometric view of TIIR building

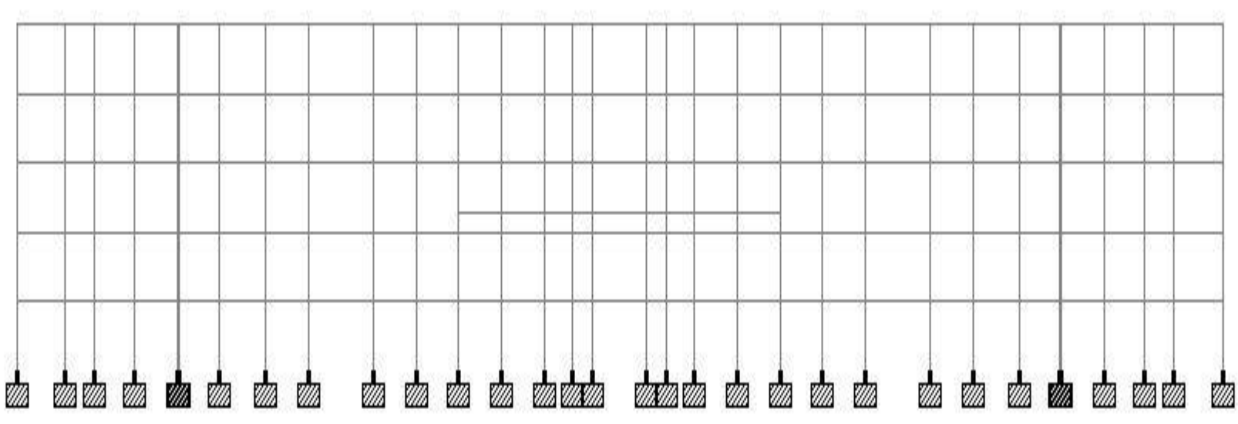

Fig3.4, +Z view of TIIR building

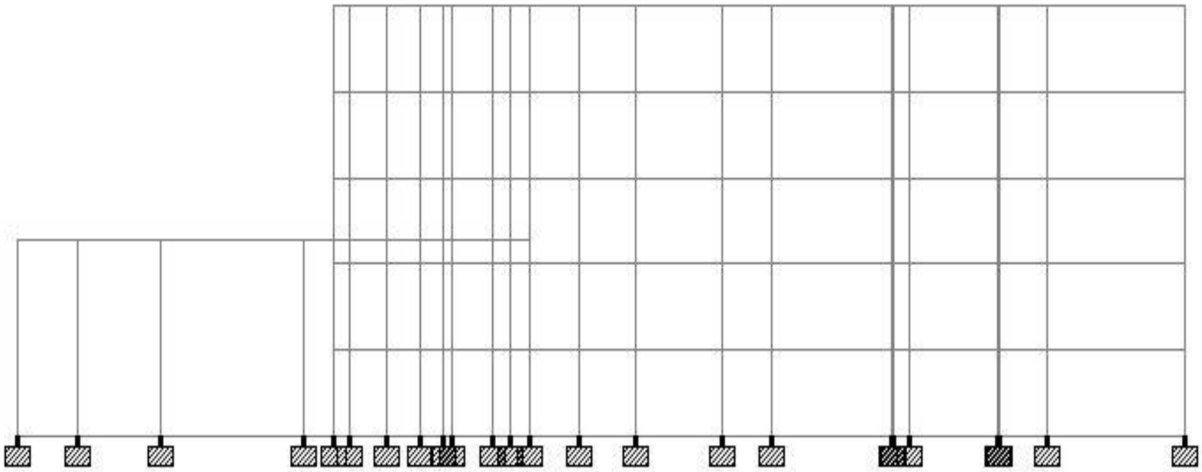

Fig3.5, +X view of TIIR building

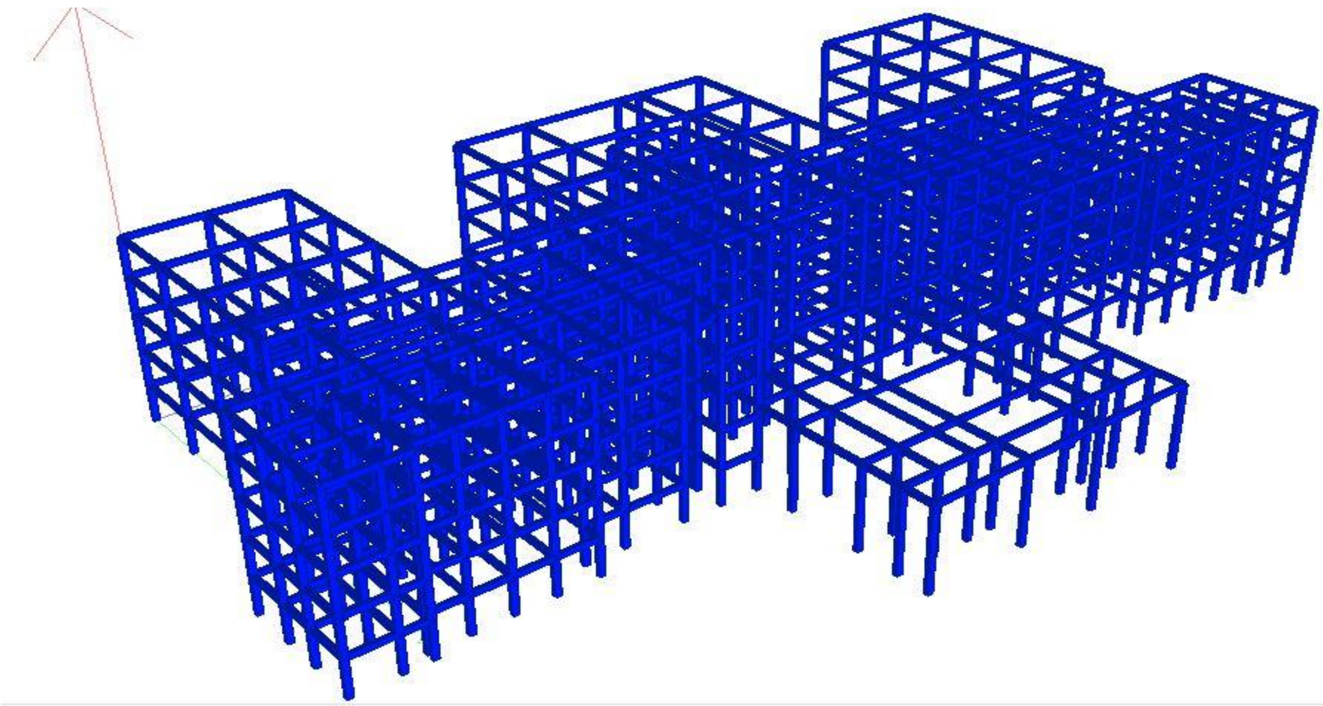

Fig3.6, 3D view of TIIR building

3.2 Materials Property

I have used M_{25} concrete and Fe_{415} steel while analyzing the given school buildings.

Table 3.1 Concrete property

Young's Modulus (E)	21718.5 MPa
Poisson's Ratio (nu)	0.17
Density	24.0261 KN/m^3
Thermal coefficient (a)	10^{-5} /ċ
Critical Damping	0.05

Table 3.2 Steel property

Young's Modulus (E)	205000 MPa
Poisson's Ratio (nu)	0.3
Density	76.8195 KN/m^3
Thermal coefficient (a)	$1.2*10^{-5}$ /ċ
Critical Damping	0.03

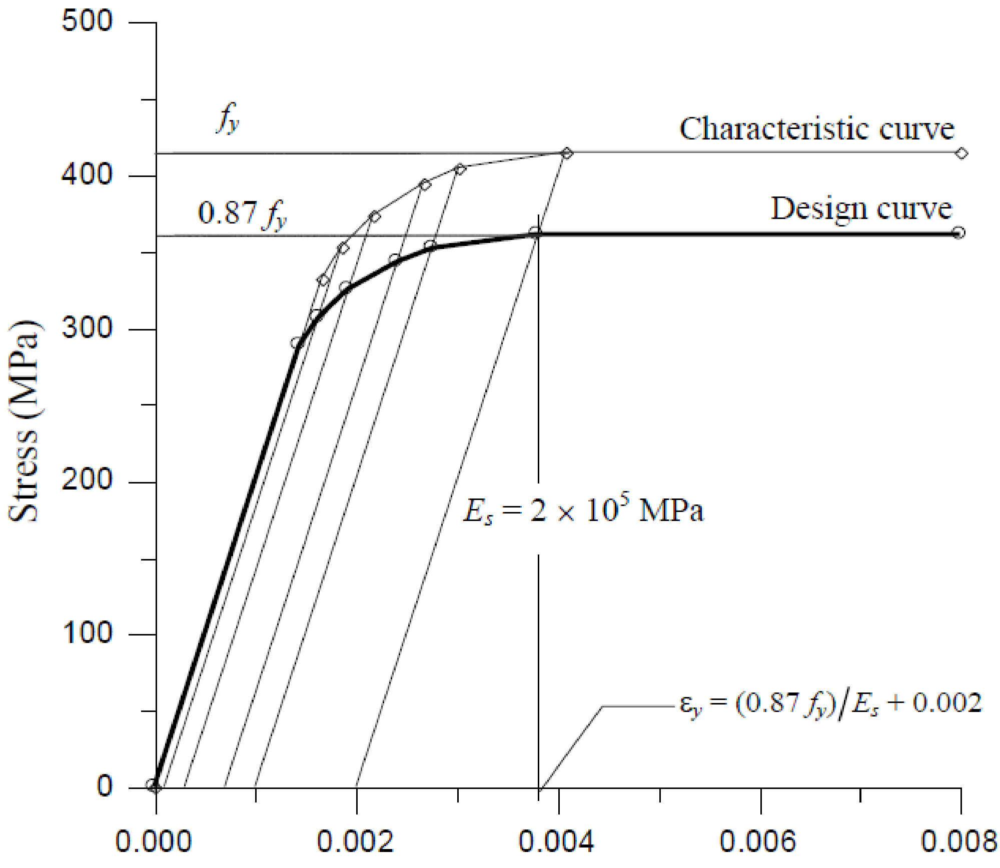

Fig 3.7, Steel property

3.3 loads on structure

The structure is analyzed and designed for live load, dead load, and seismic load as per IS-1893-2002. The following figures show the different load acting on TIIR building

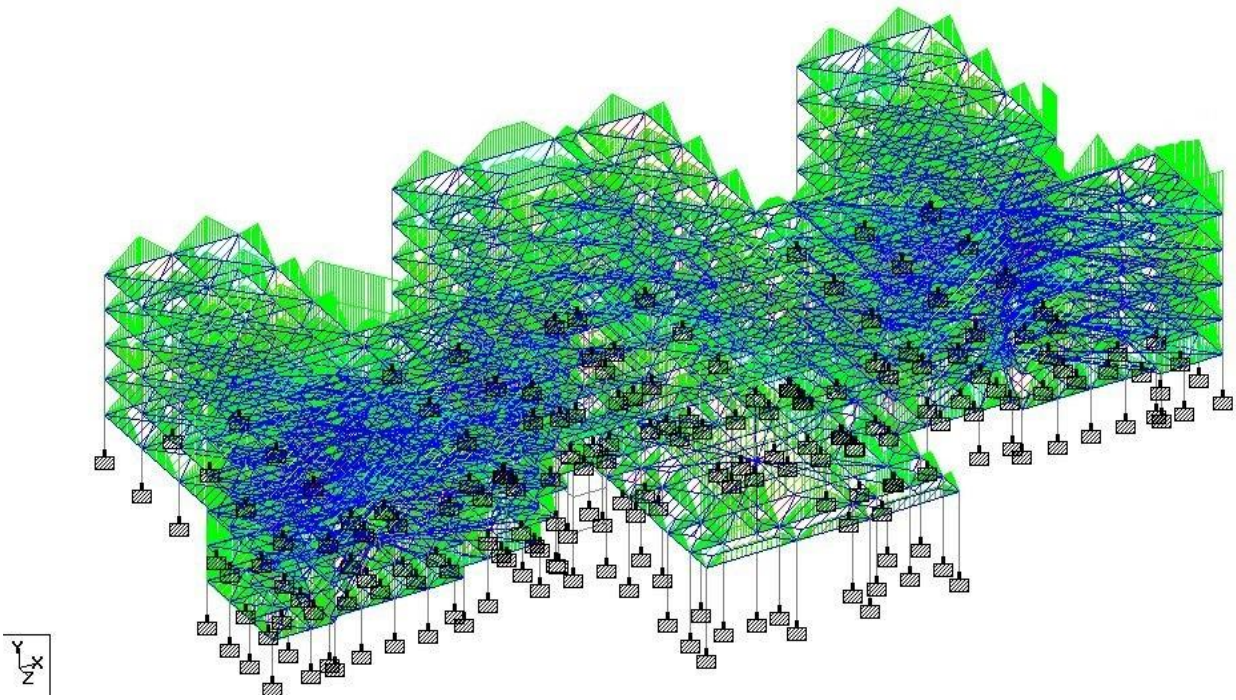

Fig3.8, dead load and live load are acting on TIIR building

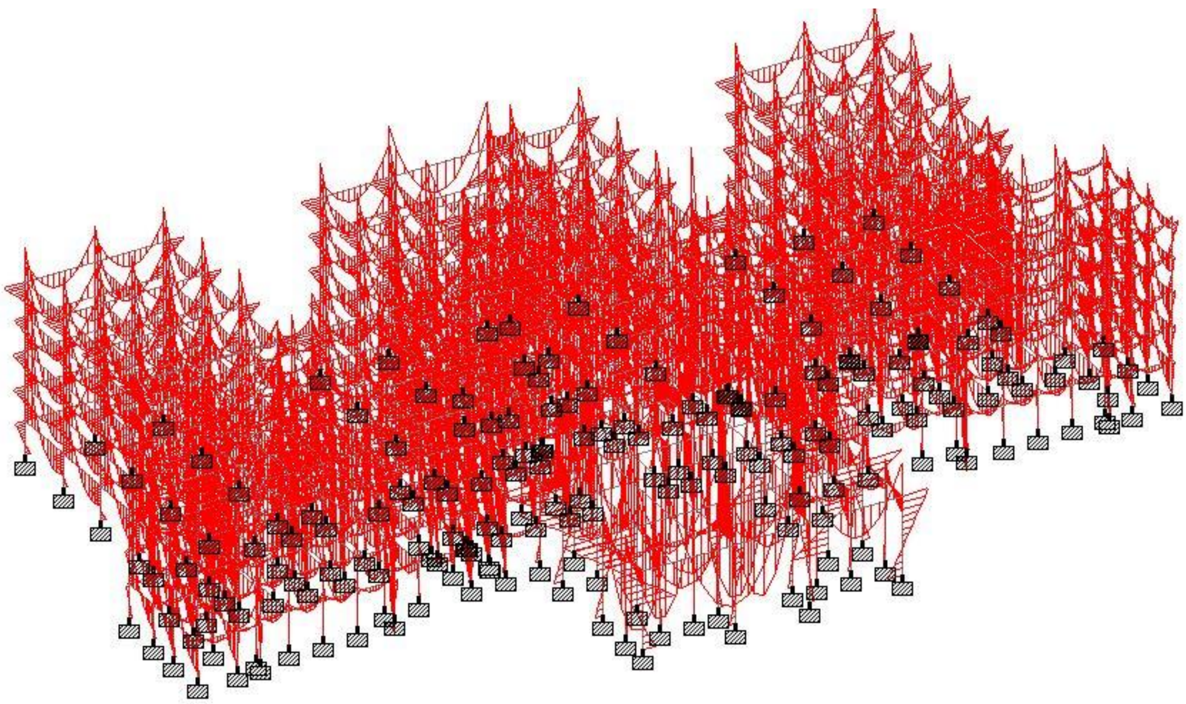

Fig3.9, bending diagram due to dead load and live load

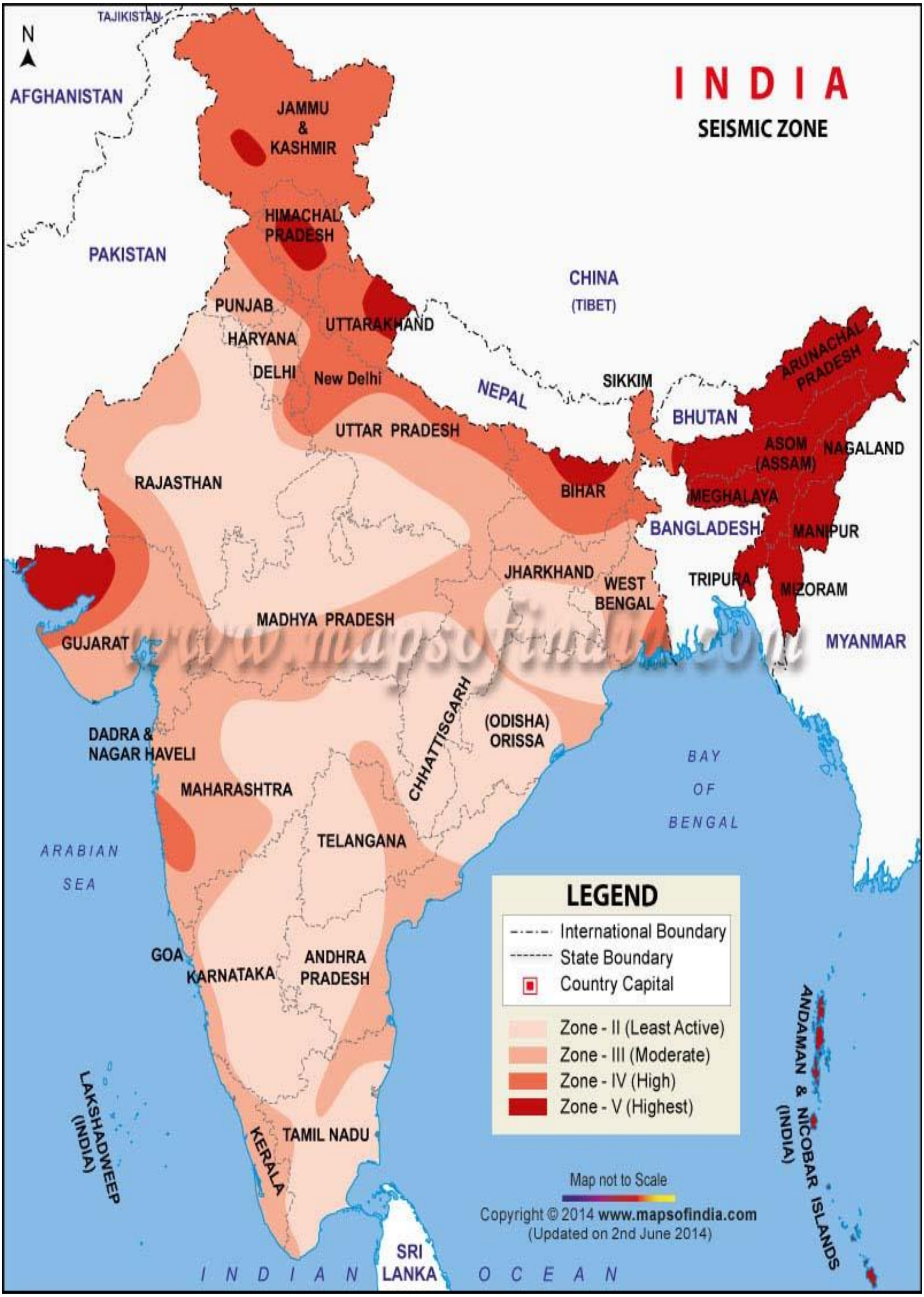

Fig3.10, Seismic zones of India

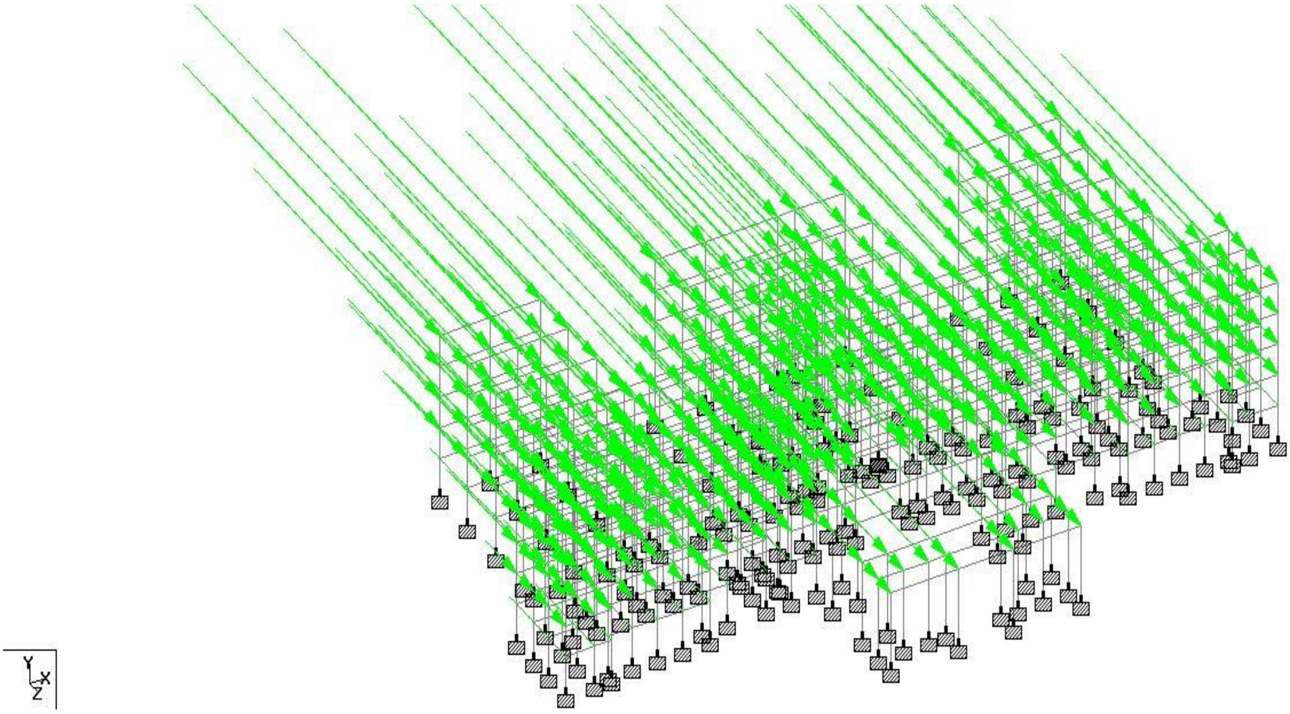

Fig3.11, seismic load acing from +Z direction(Isometirc view)

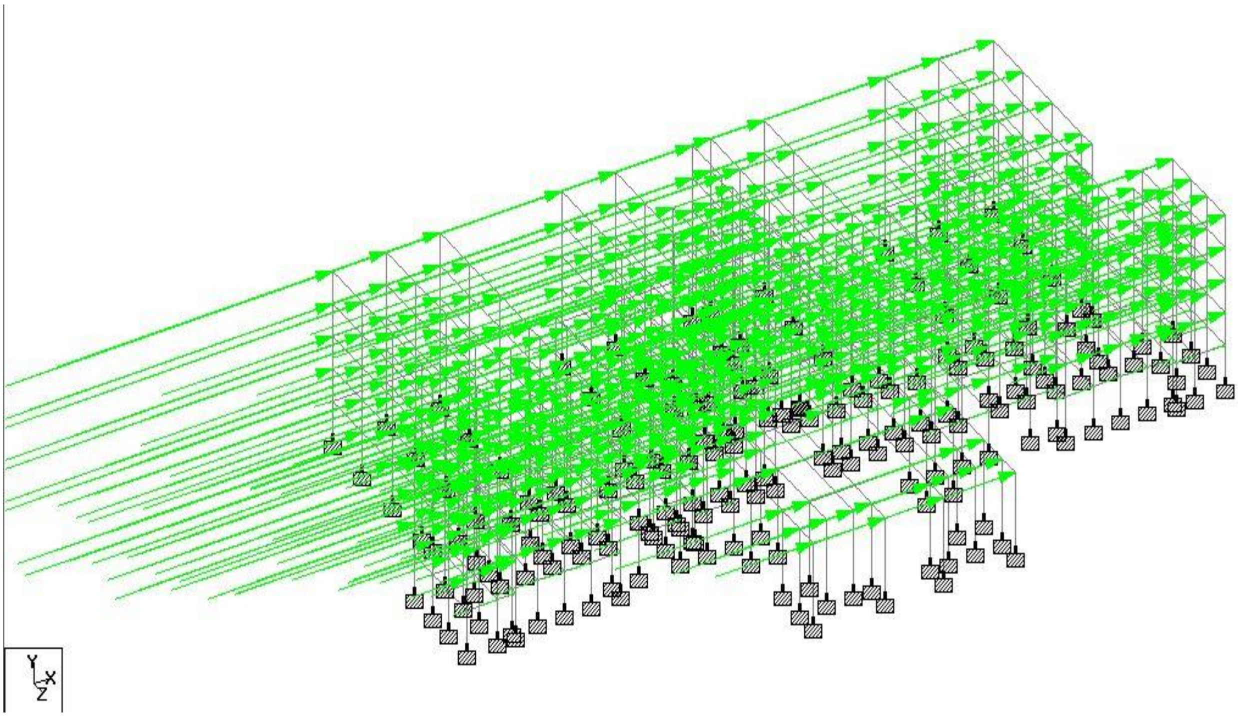

Fig3.12, seismic load acting from +X direction (Isometric view)

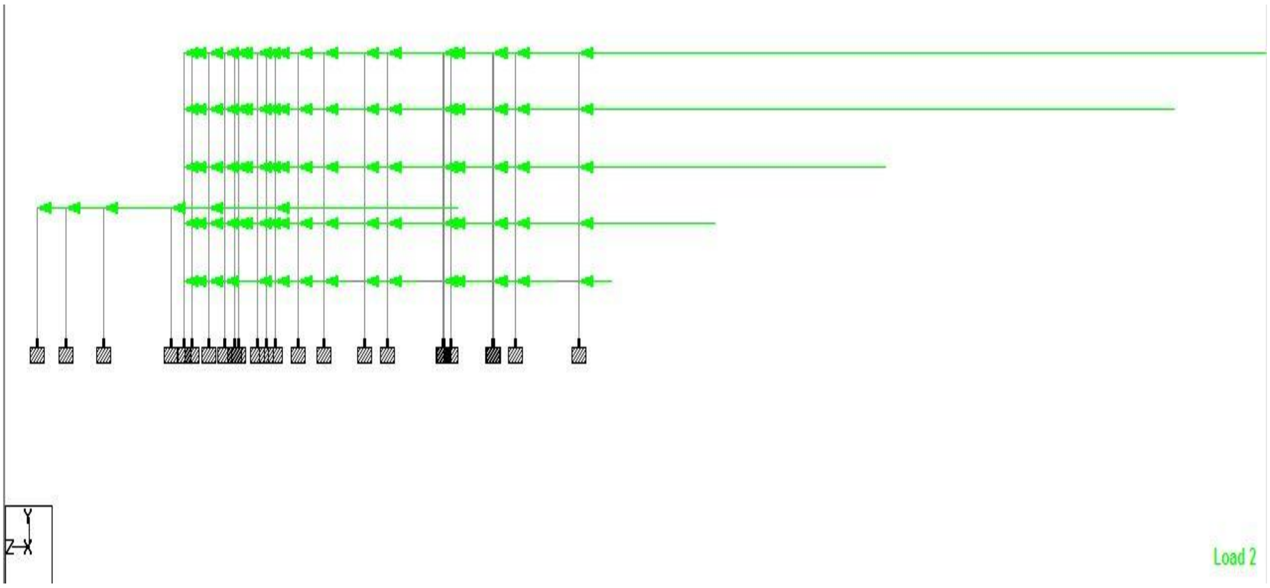

Fig3.13, seismic load acting from Z direction (elevation)

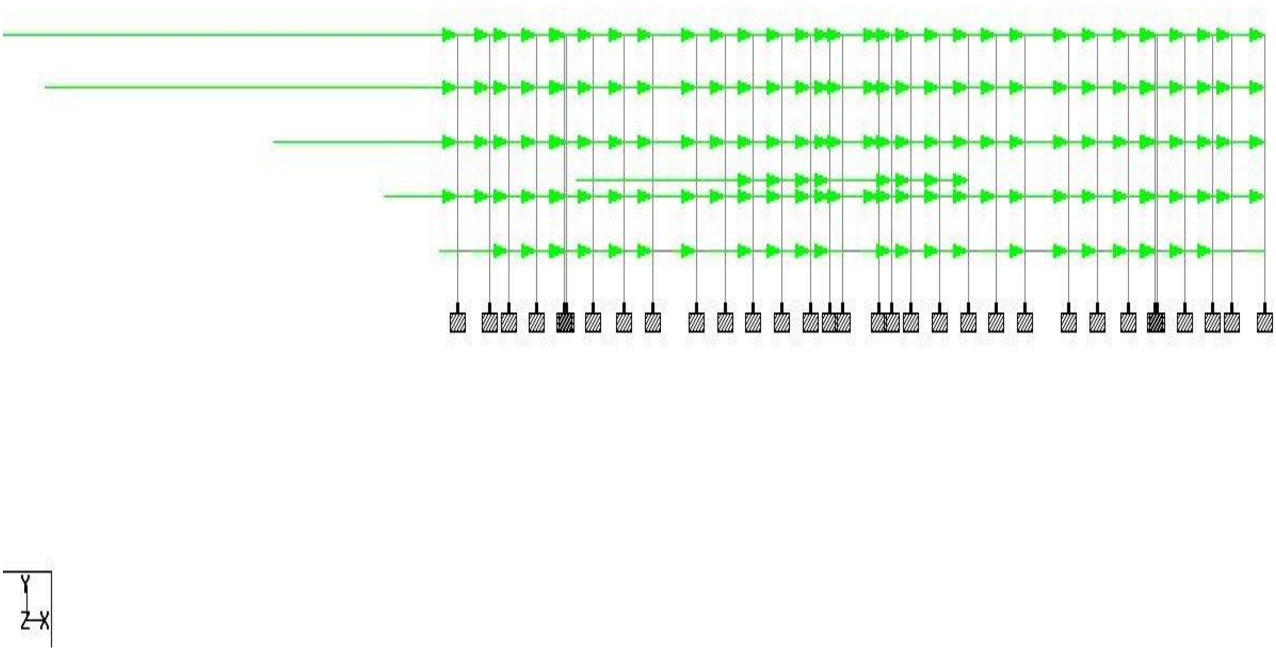

Fig3.14, seismic load acting from +X direction (elevation)

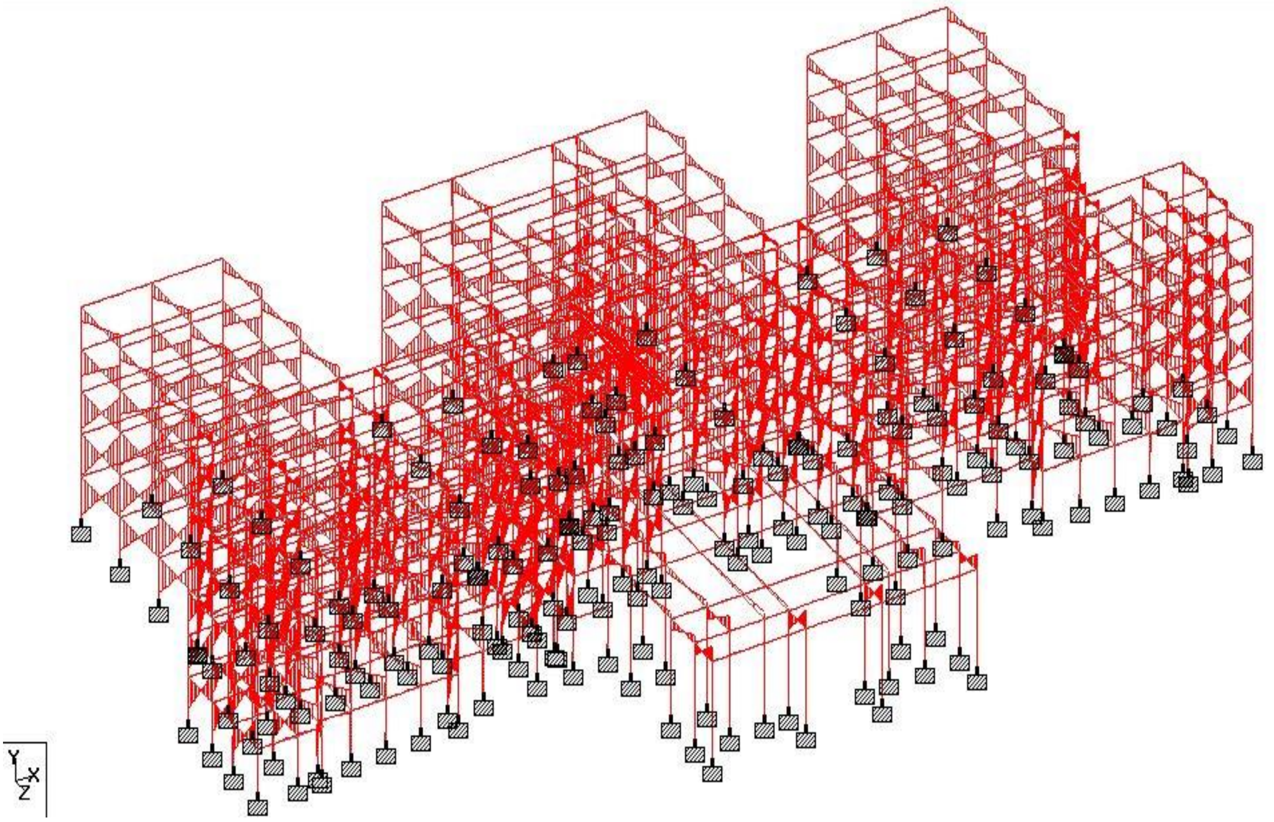

Fig 3.15, bending due to seismic force from +Z direction

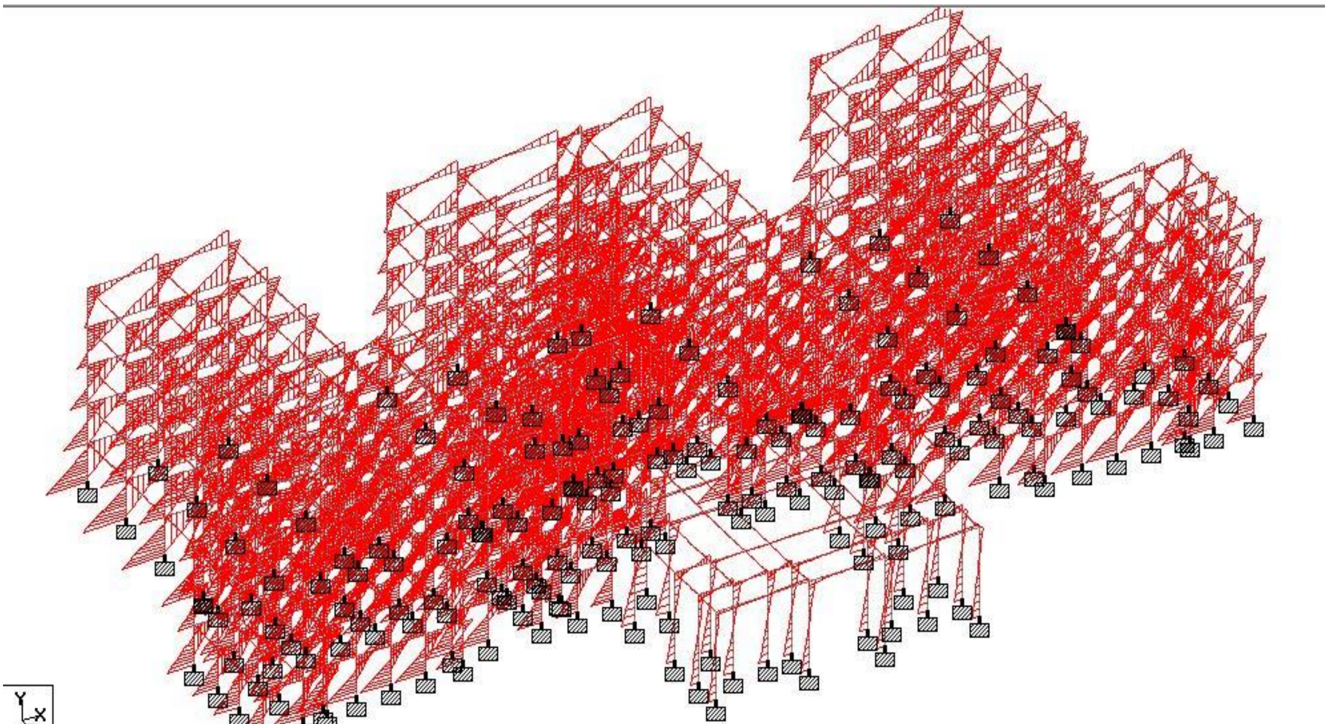

Fig 3.16, bending due to seismic load from+X direction

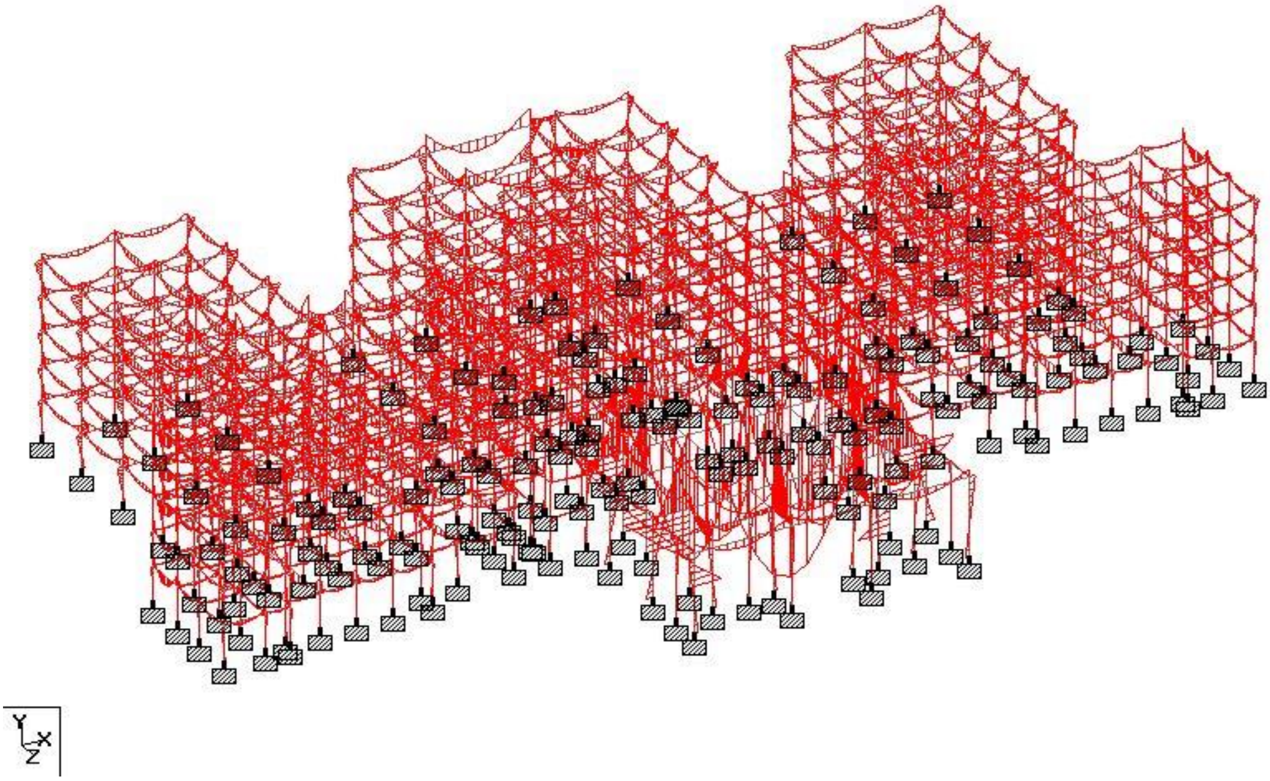

Fig 3.17, bending du auto load combination 5^{th}

Summary of support reactions are shown in the following table

	Node	L/C	Horizontal	Vertical	Horizontal	Moment		
			Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	218	5 GENERATE	**115.772**	1072.228	-1.749	-9.418	0.352	-306.293
Min Fx	219	5 GENERATE	**-115.758**	1072.261	-1.745	-9.401	-0.362	306.232
Max Fy	116	5 GENERATE	1.340	**2382.394**	-28.206	-31.432	0.090	-2.247
Min Fy	180	5 GENERATE	3.716	**-134.117**	15.044	19.177	-1.296	-9.823
Max Fz	79	5 GENERATE	12.997	935.268	**54.227**	98.634	-2.615	-15.051
Min Fz	212	5 GENERATE	-4.775	581.367	**-181.036**	-497.272	8.542	12.716
Max Mx	79	5 GENERATE	12.997	935.268	54.227	**98.634**	-2.615	-15.051
Min Mx	212	5 GENERATE	-4.775	581.367	-181.036	**-497.272**	8.542	12.716
Max My	212	5 GENERATE	-4.775	581.367	-181.036	-497.272	**8.542**	12.716
Min My	216	5 GENERATE	4.781	581.359	-181.034	-497.263	**-8.544**	-12.742
Max Mz	219	5 GENERATE	-115.758	1072.261	-1.745	-9.401	-0.362	**306.232**
Min Mz	218	5 GENERATE	115.772	1072.228	-1.749	-9.418	0.352	**-306.293**

Table 3.3, summary of support reaction

Summary of beam end forces are shown in the following table

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	617	5 GENERATE	116	2382.394	-1.340	-28.206	0.090	31.432	-2.247
Min Fx	449	5 GENERATE	254	**-197.734**	-3.716	15.044	-1.296	101.173	19.902
Max Fy	516	5 GENERATE	266	99.663	**423.328**	-0.001	0.000	-0.228	1521.050
Min Fy	516	5 GENERATE	267	99.663	**-423.327**	-0.001	0.000	-0.242	1521.041
Max Fz	1131	5 GENERATE	615	490.980	-16.306	**243.065**	-35.500	1010.362	19.630
Min Fz	455	5 GENERATE	212	581.367	4.775	**-181.036**	8.542	497.272	12.716
Max Mx	501	5 GENERATE	263	4.600	126.240	-23.418	**228.423**	46.713	27.833
Min Mx	507	5 GENERATE	265	4.615	126.234	23.418	**-228.422**	-46.713	27.822
Max My	1131	5 GENERATE	248	483.028	-16.306	243.065	-35.500	**1253.427**	35.935
Min My	455	5 GENERATE	260	517.750	4.775	-181.036	8.542	**-951.019**	-25.485
Max Mz	516	5 GENERATE	266	99.663	423.328	-0.001	0.000	-0.228	**1521.050**
Min Mz	462	5 GENERATE	267	1008.644	115.758	-1.745	-0.362	-4.557	**-619.836**

Table 3.4, Summary of beam end forces

Critical node displacements are shown in the following table

			Horizontal	Vertical	Horizontal	Resultant	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	1036	7 GENERATE	13.336	-1.878	-0.020	13.468	0.000	-0.000	-0.001
Min X	619	5 GENERATE	**-1.105**	-0.117	1.204	1.639	-0.000	0.000	-0.000
Max Y	254	5 GENERATE	0.010	**0.272**	8.058	8.063	0.004	0.000	-0.000
Min Y	1132	5 GENERATE	0.205	**-5.020**	-1.211	5.168	-0.001	-0.000	-0.000
Max Z	1104	2 LOAD CAS	0.394	0.002	**12.208**	12.215	0.001	0.000	-0.000
Min Z	608	5 GENERATE	0.290	-1.094	**-3.085**	3.286	0.004	-0.000	0.000
Max rX	245	5 GENERATE	0.003	-1.205	8.678	8.761	**0.019**	-0.000	-0.001
Min rX	264	5 GENERATE	-0.019	-0.900	6.445	6.507	**-0.022**	0.001	-0.001
Max rY	264	5 GENERATE	-0.019	-0.900	6.445	6.507	-0.022	**0.001**	-0.001
Min rY	260	5 GENERATE	0.016	-0.900	6.446	6.509	-0.022	**-0.001**	0.001
Max rZ	267	5 GENERATE	-0.251	-1.703	1.850	2.528	0.000	0.000	**0.012**
Min rZ	266	5 GENERATE	0.243	-1.703	1.853	2.529	0.000	-0.000	**-0.012**
Max Rs	1078	7 GENERATE	13.256	-3.396	-0.031	**13.684**	0.000	-0.000	-0.000

Table 3.5, Summary of node displacement

4 Reinforce Concrete Design

4.1 Detailing of beam and column

In Technology Innovation and Industry Relations (TIIR) building, M_{25} and Fe_{415} are used. Two types of section are used .beam section (0.45x0.4) and columns (0.5x0.45).

From those beams and columns on from each are chosen for showing their reinforcement details.

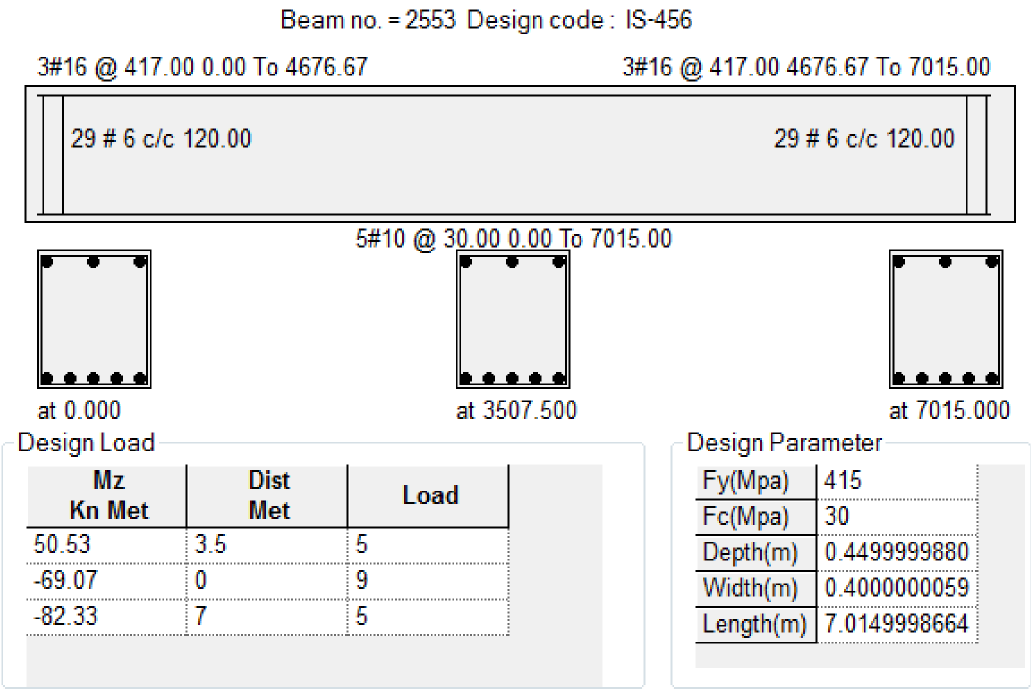

Fig 4.1, reinforcement details of beam

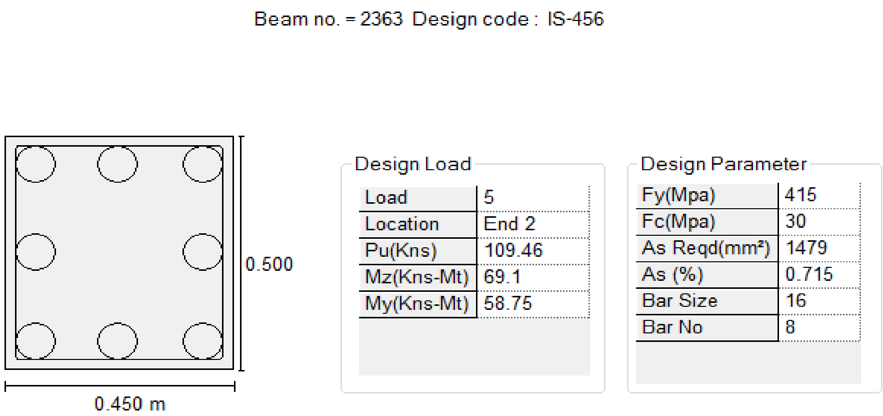

Fig 4.2, reinforcement details of column

5 Seismic evaluation

5.1 Equivalent static performance

In recent years the topic of seismic loads and analysis has become of increasing importance in both Europe and the United States. This is due largely to the frequency of large magnitude seismic events that have been witnessed, often in large metropolitan areas, typically resulting in tragic loss of life. As a direct result greater efforts have been made to understand and quantify loads that might be experienced during an earthquake.

This interest also extends to the expanding boundaries of science. Optical and radio telescopes are being continuously used to increase and improve humanity's knowledge of the universe surrounding us. By their very nature these instruments are extremely sensitive to vibratory disturbances. They are also located in remote regions such as northern Chile or Hawaii which are active seismic zones. Proper consideration of seismicity is important in guaranteeing a long design life for the telescope.

Historically, seismic loads were taken as equivalent static accelerations which were modified by various factors, depending on the location's seismicity, its soil properties, the natural frequency of the structure, and its intended use. The method was refined over the years to enable increasingly adequate designs. The underlying design philosophy was basically unchanged; some modifications were made to the coefficients as a result of strong earthquakes. Other modifications to account for new information were introduced by specifying acceptable structural details for different construction materials.

However, this method was developed in order to design buildings and not telescopes. These two applications have some important differences. Buildings have longer periods of vibration. They are also designed as regular frames and can be simplified as two-dimensional frames. Telescopes, on the other hand, are deflection controlled structures with short periods of vibration, composed largely of orthogonal, closely spaced modes.

All design against earthquake effects must consider the dynamic nature of the load. However, for simple regular structures, analysis by equivalent linear static methods is often sufficient. This is permitted in most codes of practice for regular, low- to medium-rise buildings and begins with an estimate of peak earthquake load calculated as a function of the parameters given in the code. Equivalent static analysis can, therefore, work well for low- to medium-rise buildings without significant coupled lateral–torsional modes, in which only the first mode in each direction is of significance. Tall buildings (over, say, 75 m), where second and higher modes can be important, or buildings with torsional effects, are much less suitable for the method, and both Euro code 8 and IBC require more complex methods to be used in these circumstances. However, it may still be useful, even here, as a 'sanity check' on later results using more sophisticated techniques.

This approach defines a series of forces acting on a building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves. The response is read from a design response spectrum, given the natural frequency of the building (either calculated or defined by the building code). The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces (e.g. force reduction factors).

5.2 Summary and Conclusion

The all loads are applied on the structure according to IS1893 (2002) and different combination of loads were generated by STAAD Pro software .by considering the all specification for 3nd zone in seismic zones of India. The amount of concrete and reinforcement with different diameters which are suggested by Software are as follows

Total volume of concrete required = 1967.17m^3

Bar diameter (in mm)	Weight (in N)
6	168899.98
8	120480.06
10	241525.55
12	330177.47
16	84288.70
20	66666.16
25	18887.04
Total weight	1030925.00

Table 5.1, details of reinforcement

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